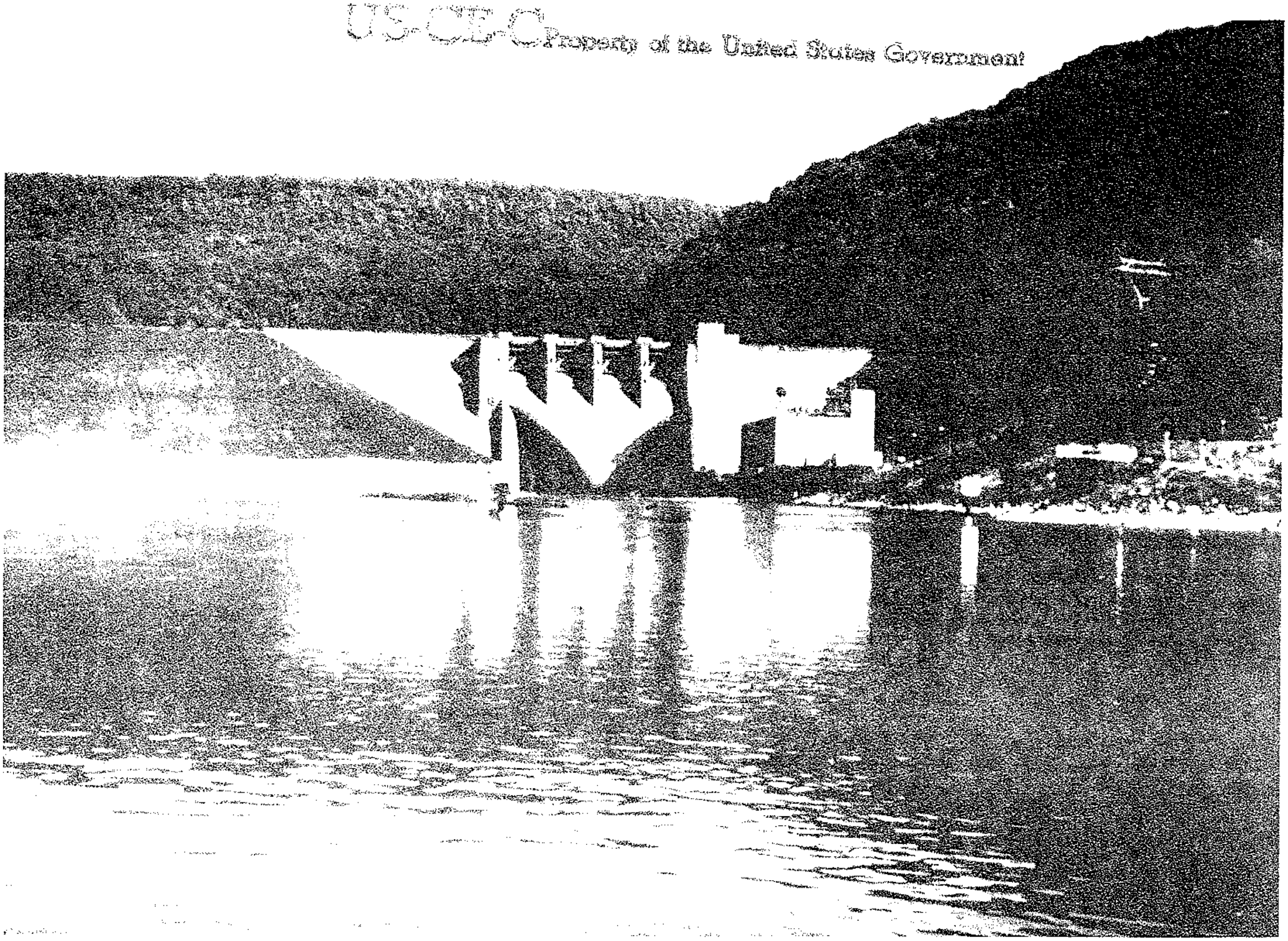
EWQOS

ENVIRONMENTAL & WATER QUALITY OPERATIONAL STUDIES

US Army Corps of Engineers

INFORMATION EXCHANGE BULLETIN

VOL E-82-6 SEPT 1982



Many of the water quality problems facing the Corps cannot be adequately solved with a one-dimensional model, but require a two-dimensional approach to provide realistic and defensible solutions. The following two articles describe the development of such a model proceeding from a hydrodynamic model that serves as the basis for the water quality model.

A MULTIDIMENSIONAL RESERVOIR WATER QUALITY MODEL

*Marc C. Johnson and Jack B. Waide**

In many CE reservoirs, significant and pronounced variations of water quality parameters occur along both the vertical and horizontal axes of the reservoir. Adequate solution of water quality problems in these reservoirs requires a two-dimensional water quality model. This article describes preliminary results of developmental work on such a model, called CE-QUAL-R2, being conducted under EWQOS Task IC.2.

One of the objectives of the Environmental and Water Quality Operational Studies (EWQOS) is to develop numerical models that incorporate biological, chemical, and hydrodynamic algorithms and to evaluate the models for reliable and practical application to environmental quality problems. Multidimensional numerical models for reservoirs are being addressed in EWQOS Task IC.2.

PRELIMINARY RESULTS

A period coinciding with a 30-day field study during May and June 1977 at DeGray Lake, Arkansas (Figure 1), was chosen for initial testing of the preliminary water quality transport model, CE-QUAL-R2. Detailed morphometric data and time-varying hydrometeorological data were collected as required for model inputs.

The model represents reservoir morphometry with computational cells of equal length and thickness, but of variable width. For this study, DeGray Lake was divided into 32 cells along the length of the reservoir, each 994 m long and 2 m thick (Figure 2). The time-varying hydrometeorological data included inflows, outflows, dew point and equilibrium temperatures, heat exchange coefficients, solar radiation, and wind speeds.

Near the end of the 30-day study period, a storm event occurred, and data were collected and used to analyze CE-QUAL-R2's ability to simulate the storm event. Results of the simulation showed that the model correctly predicted inflow placement in a stratified pool, travel times of constituents that appeared in the inflow at different times during the storm hydrograph, dilution of inflow constituents, and die-off of fecal coliforms (Johnson et al. 1981).

Simulation results are shown in Figures 3-6. Observed and predicted longitudinal turbidity profiles for DeGray Lake are shown in Figures 3 and 4, respectively, for 18 June 1977, two days after the storm inflow. Both profiles showed an interflow entering at an elevation of approximately 120 m mean sea level (msl) with its leading edge near Station 9. Velocity vectors predicted for this day also showed a strong inflow current with a reverse current above it (Figure 5). The model accurately predicted the increase in fecal coliform concentrations from 16 to 18 June and the subsequent decrease from 18 to 21 June (Figure 6). Decay rates for the fecal coliform simulations were taken from previous field observations (Thornton et al. 1980).

In other simulations for the 30-day period, total phosphorus and nitrate-nitrogen were modeled as conservative substances to examine the importance of dilution and mixing in reducing their in-pool concentrations. Total phosphorus concentrations peaked on the rising side of the hydrograph, while

* Johnson, Research Hydraulic Engineer, and Waide, Research Ecologist, are assigned to the Ecosystem Research and Simulation Division's Water Quality Modeling Group of the Environmental Laboratory.

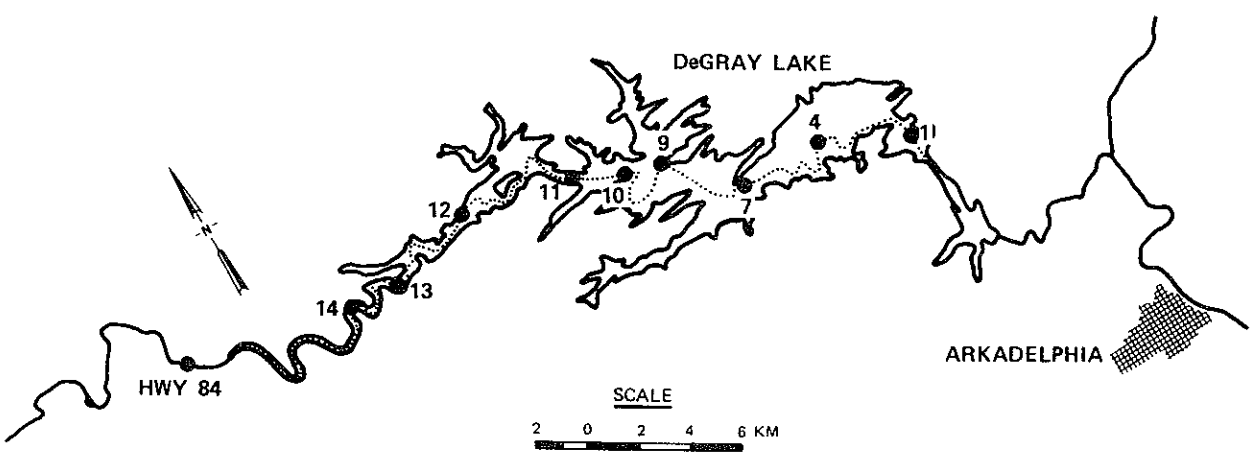


Figure 1. Locations of field-measurement stations in DeGray Lake, Arkansas

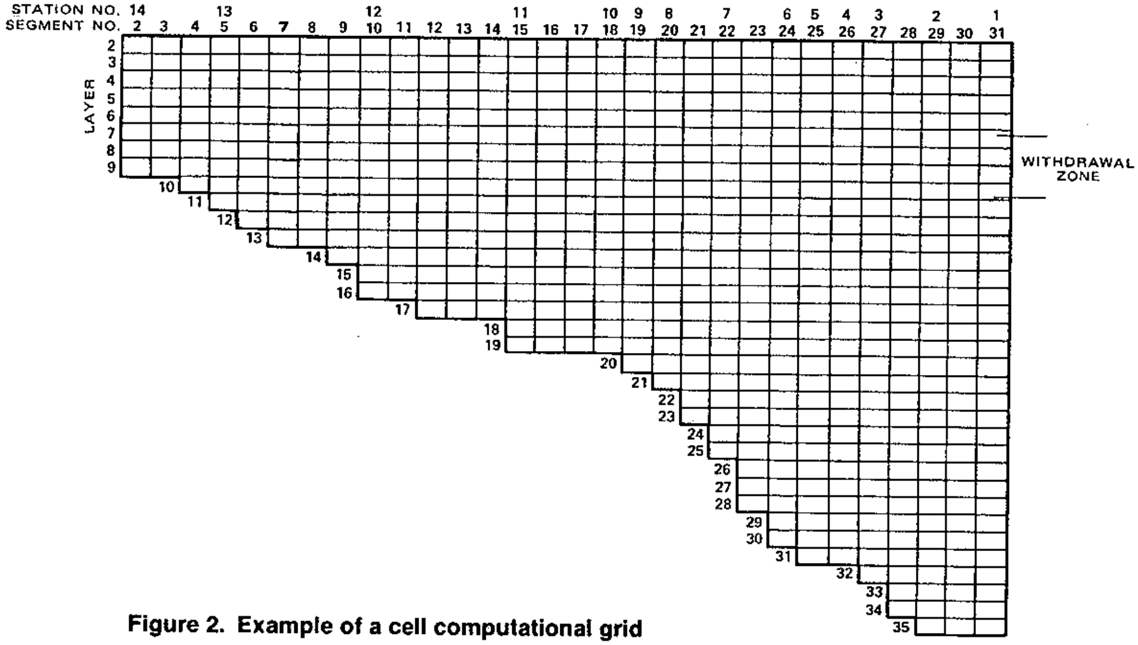


Figure 2. Example of a cell computational grid

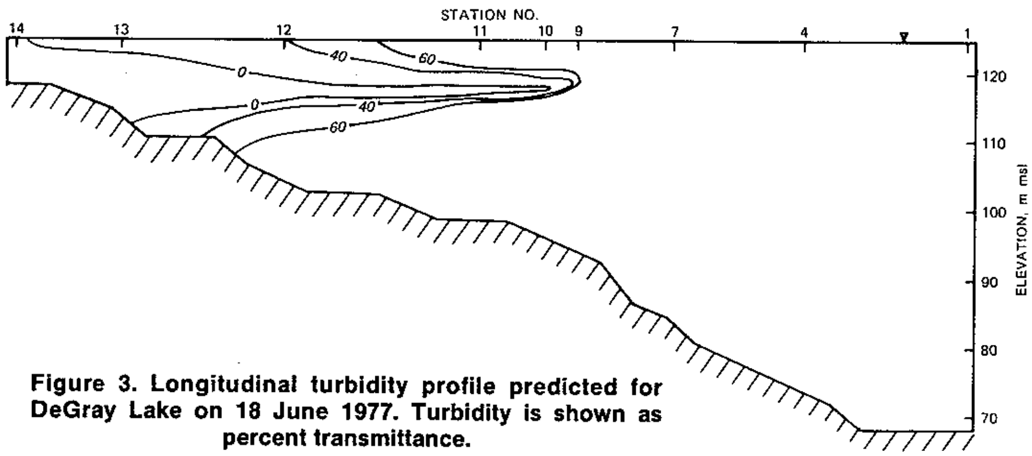


Figure 3. Longitudinal turbidity profile predicted for DeGray Lake on 18 June 1977. Turbidity is shown as percent transmittance.

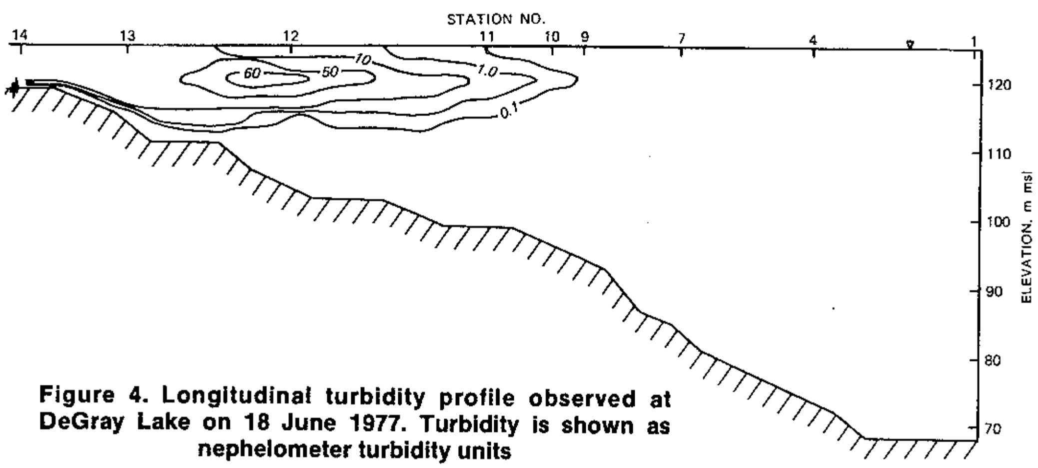


Figure 4. Longitudinal turbidity profile observed at DeGray Lake on 18 June 1977. Turbidity is shown as nephelometer turbidity units

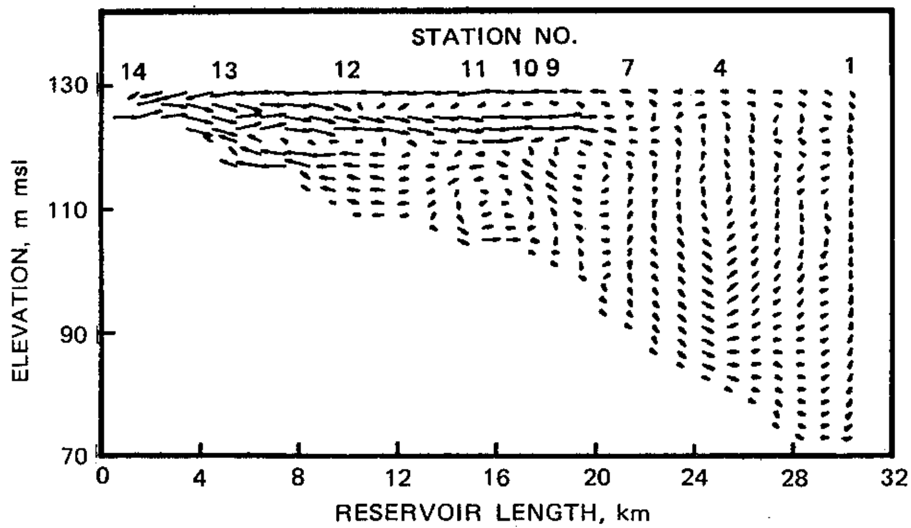


Figure 5. Velocity vectors predicted for DeGray Lake on 18 Jun 1977

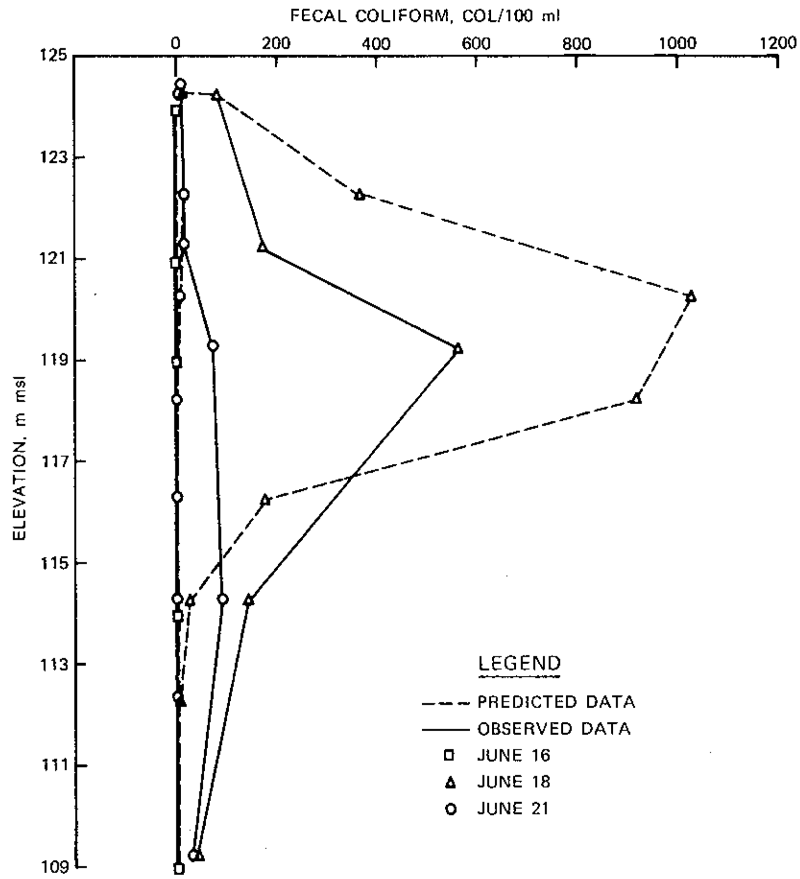


Figure 6. Fecal coliform concentrations observed and predicted for DeGray Lake, June 1977

nitrate-nitrogen concentrations peaked on the falling limb of the hydrograph; as a result, the two constituent plumes had different travel times through the reservoir. The model correctly simulated this difference, positioning the leading edge and center of mass of each constituent plume at the observed location. Simulated concentrations of total phosphorus and nitrate-nitrogen were significantly reduced by dilution and mixing, but not to the levels observed. This difference indicates that other physical, chemical, and biological processes are important in reducing in-pool concentrations. Improvements to the chemical and biological algorithms in this preliminary version of CE-QUAL-R2 are being instituted.

FUTURE WORK

Chemical and biological algorithms previously used in the one-dimensional water quality model, CE-QUAL-R1, are being evaluated for incorporation into CE-QUAL-R2. Because of differences in time and space scales between one- and two-dimensional simulations and the fact that process descriptions depend on the time and space scale of model resolution, many of these algorithms will be modified before incorporating them into CE-QUAL-R2. Some modifications will also result from verification studies with CE-QUAL-R1 currently under way in Task IC.1. Test applications will be made to evaluate the modified two-dimensional algorithms, and a report is scheduled to be published in September 1984. A report on the model and a user's manual are also scheduled for release in September 1984.

Previous work has demonstrated that it is economically feasible to model reservoirs in two dimensions over a long time period. Coupled with the results of current work, which shows that water quality parameters that vary in two dimensions can be satisfactorily modeled, this demonstrates that a two-dimensional water quality model is very promising in providing additional procedures to analyze and solve reservoir water quality problems.

REFERENCES

Johnson, M. C., Ford, D. E., Buchak, E. M., and Edinger, J. E. 1981. "Analyzing Storm Event Data from DeGray Lake, Arkansas, Using LARM," presented at the ASCE 1981 Convention and Exposition, St. Louis, Mo.

Thornton, K. W., Nix, J. F., and Bragg, J. D. 1980. "Coliforms and Water Quality: Use of Data in Project Design and Operation," *Water Resources Bulletin*, Vol 16, No. 1, pp 86-92.

A MULTIDIMENSIONAL HYDRODYNAMIC MODELS RESERVOIR

M. S. Dortch*

PAST EFFORTS

A critical step in the development of a two-dimensional water quality model is an accurate and computationally-efficient method for simulating reservoir hydrodynamics. This article describes the results and current work in this area being conducted within EWQOS Task IA.4.

Previous work has included identification and evaluation by comparing numerical predictions with an underflow density current produced in the laboratory (Johnson 1981). The model most consistent with the Corps' requirements was the Edinger and Buchak (1979) two-dimensional Laterally Averaged Reservoir Model (LARM).

Emphasis was then placed on improving LARM's capabilities. These efforts have resulted in two major improvements: the capability of upstream cell addition or deletion during flooding and drawdown; and the incorporation of a Water Quality Transport Module (WQTM). These improvements, which resulted in an expanded code (LARM2), are documented in Edinger and Buchak (1982) and Buchak and Edinger (1982).

* Dortch is a Research Hydraulic Engineer in the Reservoir Water Quality Branch, Hydraulic Structures Division of the WES Hydraulics Laboratory.

RECENT FINDINGS

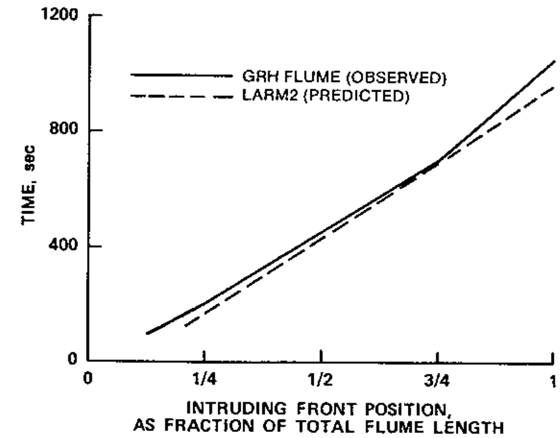
Evaluation of recent modifications and identification of potential improvements are being accomplished by comparing LARM2 predictions with various flow conditions generated in the Generalized Reservoir Hydrodynamics (GRH) flume (described in EWQOS Information Exchanges Bulletins E-79-3 and E-80-3 and by Johnson (1981)). Results from the GRH flume conveniently provide a detailed experimental database for continued evaluation of the basic LARM model and improvements. For example, this technique was used to evaluate the code's performance after incorporating the WQTM.

In the experimental phase of the study, benchmark data were obtained for both interflow and overflow density currents. Interflow and overflow density currents were created through thermal stratification and control of inflow temperature. Fluorescent dye was dissolved in the inflow water to provide a continuous conservative inflow tracer. Dye concentration and temperature measurements were obtained from the GRH flume as well as measurements of the intrusion length and the vertical thickness of the density current as a function of time.

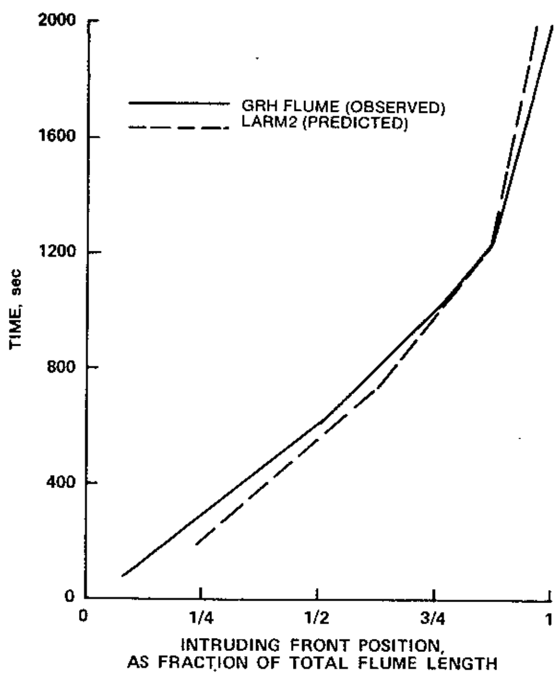
Subsequently, LARM2 was used to numerically simulate these conditions after selecting an appropriate grid size and time step. This corresponded to dividing the flume into 16 horizontal and 30 vertical segments. The time step used was 5.0 sec. Example outputs from the two numerical model simulations were flow vector plots and temperature and dye-concentration contour plots. The dye concentrations, output from the WQTM, were normalized relative to the inflow concentration.

The travel time of the computed density current was estimated by analyzing vector and contour plots that were displayed every 25 time steps. The 0.2 dye contour was chosen to represent the predicted intrusion leading front and profile because this contour location was indicative of the location of the large longitudinal velocity gradient associated with the nose of the intrusion. As indicated in Figure 1, the model predictions closely approximated the observed intrusion speeds. It is impressive that the LARM2 simulation of the interflow predicted retarding of intrusion speed near the downstream end of the flume as observed. Also, the general shape, length, and thickness of the predicted density current profiles closely resembled those observed (Figure 2).

A GRH flume dye-concentration profile was obtained at 1016 seconds into the interflow test at a station 5.33 m (17.5 ft) upstream from the dam (end

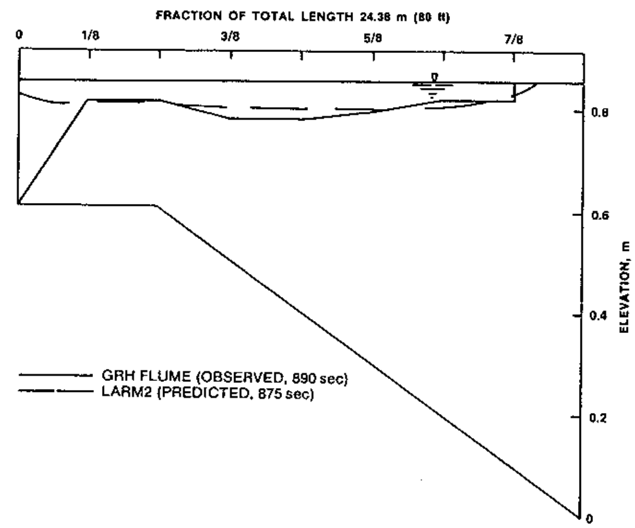


a. Overflow density currents

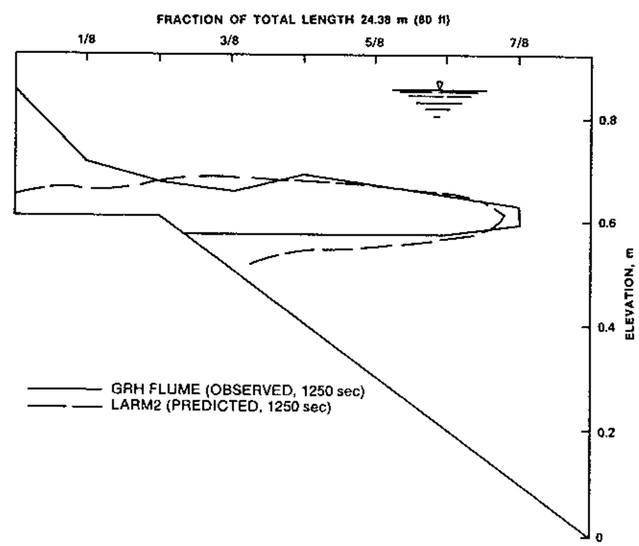


b. Interflow density currents

Figure 1. Predicted and observed intrusion speeds of overflow and interflow density currents



a. Overflow density currents



b. Interflow density currents

Figure 2. Predicted and observed overflow and interflow density current profiles

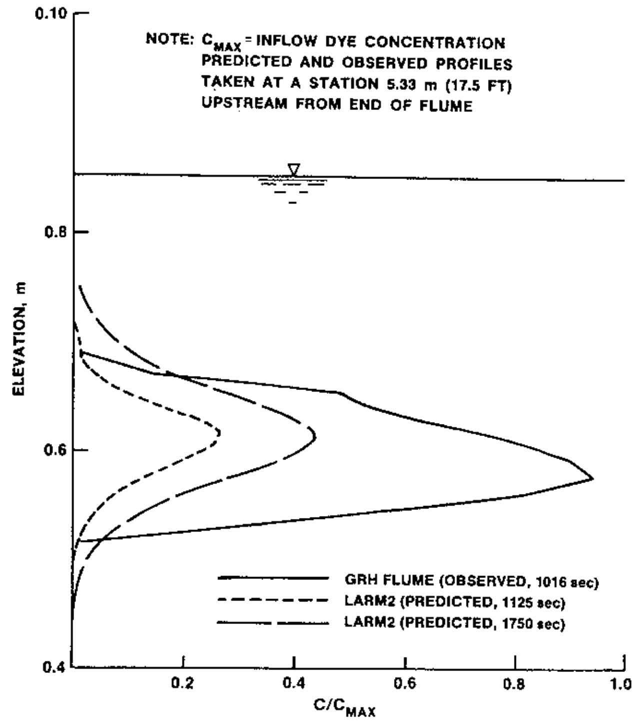


Figure 3. Predicted and observed dye concentration profiles

of the flume). Normalized dye concentrations computed by LARM2 at 1125 and 1750 sec into the simulation are shown in Figure 3. The thickness of the dye concentration profile that was predicted at 1125 seconds compared closely with that observed at 1016 sec, but the predicted maximum concentration was less than that observed. At the later time (1750 sec), the computed profile exhibited an increased peak concentration and an increased thickness. The observed profile should tend to be thicker at a later time and the peak concentration should not decrease for the continuous inflow condition.

Differences in the observed and predicted dye profiles are attributed to certain finite differencing techniques. The computed peak dye concentration increased with time, indicating longitudinal dispersion of the intruding front. Since molecular diffusion values were used for the model dispersion coefficients, at least part of the longitudinal dispersion of the intruding flow must be artificially introduced through the numerical computations. First-order upstream differencing is employed for the advective terms of the transport equation. Upstream differencing is necessary to preserve desirable transportive properties, but first-order differencing does introduce numerical dispersion. The use of higher order upstream differencing techniques or flux-corrected methods will reduce numerical dispersion and result in increased accuracy of constituent concentrations. Higher order schemes are being investigated for implementation within WQTM's present formulation.

ADDITIONAL STUDIES

Efforts are continuing to improve LARM's capabilities. One ongoing enhancement is to provide for simulation of reservoir branches. In the present form of the model, tributary inflows are allowed, but there is no provision for computations within a tributary arm or branch. This improvement will allow dynamic coupling of the tributaries with the main stream for hydrodynamic and water quality computations.

A storage and conveyance capability is being considered. It would be formulated so that the user could specify a storage conveyance width for each cell. This could improve accuracy by altering main channel velocities and constituent concentrations corresponding to the conveyance width as opposed to using the whole cross section. This would improve the applicability of the two-dimensional model to reservoirs that are characterized as more than two-dimensional. A capability to utilize a variable time step has been developed. This will provide numerical stability and finer temporal resolution for simulation of extreme (high flow) events, while reducing the computational burden by increasing the time step for less extreme (low flow) events.

The need for selective withdrawal subroutines is being evaluated and any necessary modifications will be made in the near future. It may be necessary to specify the selective withdrawal distribution as an outflow boundary condition for LARM. If needed, subroutines will be incorporated that calculate the withdrawal distribution as a function of the outflow rate, density stratification, and outlet specifications.

Current Corps practice for studing and defining the hydrodynamics of existing and proposed reservoirs is to use a combination of three-dimensional physical models and one-dimensional numerical models supplemented with available field data. The continued development of LARM will provide the Corps with an accurate and economical two-dimensional hydrodynamic predictive capability for reservoirs. A two-dimensional numerical model will complement this approach (and save much time and effort) and will provide the basis for a two-dimensional water quality model.

REFERENCES

Buchak, E. M., and Edinger, J. E. 1982. "User Guide to LARM2, a Longitudinal Vertical, Time-Varying Hydrodynamic Reservoir Model,"Technical Report in publication, prepared by J. E. Edinger Associates, Inc., for the U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Edinger, J.E., and Buchak, E. M. 1979. "A Hydrodynamic Two-Dimensional Reservoir Model: Development and Test Application to Sutton Reservoir, Elk River, West Virginia," U. S. Army Engineer Division, Ohio River, Cincinnati, Ohio.

Edinger, J. E., and Buchak, E. M. 1982. "LARM2 Developments 1979-1980," Technical Report in publication, prepared by J. E. Edinger Associates, Inc., for the U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Johnson, B. H. 1981. "A Review of Numerical Reservoir Hydrodynamic Modeling," Technical Report E-81-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This bulletin is published in accordance with AR 310-2. It has been prepared and distributed as one of the information dissemination functions of the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from EWQOS can be rapidly and widely disseminated to Corps District and Division offices as well as other Federal agencies, state agencies, universities, research institutes, corporations, and individuals. Contributions of any type are solicited from all sources and will be considered for publication as long as they are relevant to the objectives of EWQOS, i.e., to provide new or improved technology to solve selected environmental quality problems associated with Civil Works activities of the Corps of Engineers in a manner compatible with authorized project purposes. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be addressed to the Environmental Laboratory, ATTN: J.L. Mahloch, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Mississippi 39180, or call AC 601, 634-3635.

TILFORD C. CREEL
Colonel, Corps of Engineers
Commander and Director